Public Interest Energy Research (PIER) Program
FINAL PROJECT REPORT

DEMONSTRATION OF ZBB ENERGY STORAGE SYSTEMS

Prepared for: California Energy Commission
Prepared by: ZBB Energy Corporation

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Demonstration of ZBB Energy Storage Systems is the final report for contract number 500-03-031 conducted by ZBB Energy Corporation. The information from this project contributes to PIER's Transmission and Distribution Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier or contact the Energy Commission at 916-654-4287.

Table of Contents

List of Figures

List of Tables

Abstract

This report documents the demonstration of a large-scale, transportable turn-key Zinc Energy Storage System supplied by ZBB Energy Corporation, Menomonee Falls, Wisconsin at a Pacific Gas & Electric substation in San Ramon, California.

This project supports the California Energy Commission Public Interest Energy Research (PIER) Program objectives of:

- Improving the energy cost/value of California's electricity by deferring costly substation infrastructure upgrades;
- Improving the reliability, quality, and sufficiency of California's electricity by providing support to the distribution system in the form of frequency and voltage control;
- Providing greater choices for California consumers by increasing the number of new technologies providing increased reliability and sufficiency of power to consumers;
- Connecting to near-term market applications by effectively reducing barriers to commercial acceptance through conducting large-scale utility demonstration.

Key words: energy storage, ZESS, zinc-bromine, flowing electrolyte, peak shaving, deferred costs, infrastructure upgrades.

Executive Summary

Introduction

Under sponsorship of the California Energy Commission (Energy Commission) Public Interest Energy Research (PIER) Program, ZBB Energy Corporation (ZBB), Menomonee Falls, Wisconsin, was awarded a multi-year, cost-shared contract 500-03-031 to build and demonstrate a large-scale, transportable energy storage system as a utility peak shaving resource. The energy storage system incorporates an advanced battery technology integrated with a power conversion system supplied by SatCon Technology Corporation, Burlington, Ontario, Canada.

The Pacific Gas and Electric Company (PG&E) is one of the largest independently owned gas and electric utilities in the United States, serving 15 million people and served as the host utility and provided test support. Distributed Utility Associates is an energy consulting firm in Livermore, California, and conducted the testing.

Purpose

This project supports the PIER Program objectives of:

- Improving the energy cost / value of California's electricity by deferring costly substation infrastructure upgrades;
- Improving the reliability, quantity, and quality of California's electricity by providing support to the distribution system in the form of frequency and voltage control;
- Providing greater choices for California consumers by increasing the number of new technologies supplying reliability and sufficiency of power to consumers; and
- Connecting top near-term market applications by effectively reducing barriers to commercial acceptance through conducting a successful large-scale utility demonstration.

Project Objectives

This project was designed to demonstrate and evaluate the economic benefits of distribution system upgrade deferral for a minimum of 18 months. This was to be achieved by operating a Zinc Energy Storage System at a PG&E distribution node in support of substation loads during summer peak load periods, reducing the power requirements on substation transformers and other substation equipment. The system could potentially be used to supplement the power provided from the utility transmission system, reducing the substation throughput power.

The system would draw charging energy at night when demand is low and supply this energy during periods when demand is high. The delivered energy would displace more expensive on-peak generation. Thus, the Zinc Energy Storage System would effectively "shift" the energy supply and attendant cost from on-peak sources to off-peak sources. The Zinc Energy Storage System would potentially be available to utility distribution engineers in planning sufficient substation capacity to meet anticipated seasonal peaks. It would be a temporary alternative to constructing new substation capacity, a costly and capital-intensive approach. Depending upon the forecasted load growth and existing substation capacity, the Zinc Energy Storage System may allow the utility to defer new construction for one to three years. The value to the utility and its ratepayers would be the avoidance of carrying charges during the deferral period.

Project Outcomes

In February 2006, the first 500 kWh unit for the project was installed at the Distributed Utility Integration Test site in San Ramon, California. This unit was built and tested at the ZBB factory, and it passed a 10-cycle prequalification test and factory witness test by Distributed Utility Associates prior to shipment. At the Distributed Utility Integration Test site, the Zinc Energy Storage System was tested according to a pre-designed test plan, which was intended to ensure the full 2-MWh system is fully operational, that it meets the functional requirements of the substation application, and that it will perform reliably before installation at a commercial PG&E distribution substation site.

During the characterization testing of unit #1 at the Distributed Utility Integration Test site's facility, ZBB encountered a number of obstacles, which delayed the progress of the testing. After six months of testing on unit #1 and numerous discussions with the Energy Commission, it was decided to ship an entire system to replace the original unit in the field.

The second energy storage system successfully completed the Distributed Utility Integration Test plan. The test unit was found to be capable of providing 427 kWh of energy output and a peak power output of 481 kW for short durations of less than 5 minutes. Software was developed to allow the system to operate automatically in a load following mode, based on the time of day and input from the utility.

The energy storage system successfully completed 40 load following discharge cycles and 29 days of reliability testing for a 500-kWh energy storage system. The unit demonstrated the ability to automatically charge during off-peak hours, provide load following discharges when necessary and self-strip without failures or intervention during the test period. It dispatched energy to the simulated load every time that it received a signal from the PG&E simulation program software.

Following the successful completion of the reliability tests, the unit was relocated and stored for four months and then returned to its former location. The unit then repeated safety and performance tests with no loss in efficiency.

Due to delays during the course of the program, after completion of the Distributed Utility Integration Test plan, there was not sufficient time or funding to test the entire 2-MWh system in the field at a PG&E designated test site. A Data Acquisition System implementation plan was prepared to examine the economic benefits of the energy storage system, but it was not implemented since the system was not installed at a commercial PG&E distribution substation site.

Recommendations

A number of options for going forward with the program were investigated. ZBB and the Energy Commission determined that the terms of the contract 500-03-031 could not be met without a scope, deliverable and time amendment to the contract. A plan was originally developed to continue the contract with a modified scope, but the Commission later determined that there was not sufficient time or funding to amend the current contract. The best option at the time was to close out the contract and enter into a Letter of Agreement between the Energy Commission and ZBB for equipment relocation, housing and further research. The Energy Commission authorized ZBB to continue to test and demonstrate the operation of the zinc energy storage system at its facility.

Public Benefits to CA

The primary benefit from ZBB's energy storage technology to California electricity ratepayers is in the form of reduced electricity rates. The use of targeted, properly operated distributed energy storage, in amounts necessary to meet only the load increases, can be a more cost-effective alternative, deferring infrastructure upgrades and thereby reducing capital investment costs. Indirect benefits to California electricity ratepayers include distribution system support in the form of frequency and voltage control provided by energy storage systems. The net result is reduced operations and maintenance costs.

1.0 Administration

1.1 Attend Kick-off Meeting

The goal of this task was to establish the lines of communication and procedures for implementing this Agreement.

Approach or Methods:

The kickoff meeting was attended by representatives of the California Energy Commission and ZBB Energy Corporation on May 12, 2004. ZBB presented updated project budget from the original proposal, a schedule of deliverables and a list of match funds and permits to the California Energy Commission.

Outcomes or Results:

The lines of communication and procedures for implementing the project were established.

1.2 CPR Meetings

The goal of this task was to determine if the project should continue to receive Commission funding to complete this Agreement and if so, are there any modifications that need to be made to the tasks, deliverables, schedule or budget.

Approach or Methods:

Two critical project reviews were performed during this contract. CPR #1 was held at the DUIT test facility, shortly after the ZESS was delivered to the test facility on March 27, 2006. CPR #2 was held at the California Energy Commission office in Sacramento on January 18, 2007, following initial testing of the first unit at the DUIT test facility.

Outcomes or Results:

The Critical Project Review #1 revealed to satisfaction of the Commission Contract Manager that ZBB had satisfactorily complied with the work statement and demonstrated sufficient progress toward achieving its goals and objectives to warrant continued PIER financial support for the project.

Following CPR #2, the California Energy Commission required additional information including completion of the reliability test and a detailed schedule for completing the project before providing a determination for CPR #2.

After the completion of the reliability test, and upon the positive recommendations from CEC Energy System Integration Team Lead, Key Partner PG&E, and MOU 500-03-100 partner U.S. Department of Energy, the Commission Contract Manager determined that ZBB had satisfactorily complied with the work statement and demonstrated sufficient progress toward achieving its goals and objectives to warrant continued PIER financial support for the project.

However, the Commission Contract Manager determined that under the schedule of deliverables ZBB would not be able to meet the terms of the contract. Therefore, to demonstrate and evaluate the economic benefits of distribution system upgrade deferral, a scope, deliverable and time amendment would be needed to achieve the goals of the contract.

1.3 Final Meeting

The goal of this meeting was to close out the Agreement.

Approach or Methods:

ZBB presented information to the Energy Commission Contract Manager and received a determination on the final status of the program.

Outcomes or Results:

The final meeting for the contract was performed on March 27, 2008. The Energy Commission entered into a Letter of Agreement with ZBB for equipment relocation, housing and further research. The Energy Commission authorized ZBB to continue to test and demonstrate the operation of the ZESS at ZBB's facility.

1.4 Monthly Progress Reports

The goal of this task was to periodically verify that satisfactory and continued progress was made towards achieving the research objectives of the Agreement.

Approach or Methods:

ZBB submitted reports to the California Energy Commission every month to review the progress toward achieving the goals of the Agreement.

Outcomes or Results:

The outcome of this task was to transfer information and to keep the Energy Commission updated on the progress of the program. ZBB prepared and submitted monthly progress reports which summarized all agreement activities conducted for each month.

1.5 Test Plans, Technical Reports and Interim Deliverables

The goal of this task is to set forth the general requirements for submitting test plans, technical reports and other interim deliverables, unless described differently in the Technical Tasks.

Approach or Methods:

Prepare and submit test plans, technical reports and deliverables to the Energy Commission.

Outcomes or Results:

All test plans, technical reports and deliverables submitted by ZBB to the Energy Commission were accepted.

1.6 Final Report

The goal of this task was to prepare a comprehensive written Final Report that describes the original purpose, approach, results and conclusions of the work done under this Agreement. The Commission Contract Manager then reviews and approves the Final Report. The Final Report must be completed on or before the termination date of the Agreement.

Approach or Methods:

This document comprises the final report for the program.

Outcomes or Results:

The final report was submitted to the Energy Commission and approved.

1.7 Identify and Obtain Matching Funds

The goal of this task was to ensure that the match funds planned for this Agreement are obtained for and applied to this Agreement during the term of this Agreement.

Approach or Methods:

ZBB determined Key partners and the match funds from each source of funding. ZBB presented a letter on October 6, 2004 describing the match funds for the program.

Outcomes or Results:

ZBB Energy Corporation as the prime contractor was responsible for $452,700 of matching funds toward the California Energy Commission Public Interest Energy Research (PIER) Program. The contract also called for $150,000 of matching funds to be contributed by Key Partners. All matching funds were contributed to the program. In addition, the 3% commitment to the DVBE was completed.

1.8 Identify and Obtain Required Permits

The goal of this task was to obtain all permits required for work completed under this Agreement in advance of the date they are needed to keep the Agreement schedule on track.

Approach or Methods:

ZBB discussed permitting issues with PG&E prior to installing the system at the DUIT demonstration test site. ZBB presented a letter on September 30, 2004 describing the permit requirements for the program.

Outcomes or Results:

The Energy Storage Project was conducted completely within the bounds of PG&E's facilities, both at the test facility in San Ramon and at the demonstration site, which was expected to be inside the fenced grounds of a PG&E substation. No air permits or regulatory approvals (either local or state) were necessary.

2.0 Assemble Storage System

The goal of this task was to assemble all components and subsystems into a complete, turnkey ZESS. The system will be based on ZBB zinc-bromine battery technology. The application size determined by the end-user, PG&E, is 2 MWh of storage, coupled to a power conversion system "PCS" capable of 2 MW output.

Approach or Methods:

50-kWh Module Description

The building block for the ZBB technology is a 50-kWh module, consisting of three cell stacks connected electrically in parallel, a control system, a pair of electrolyte storage tanks and pumps and plumbing for circulating the electrolyte. Each module is rated at 50kWh (direct current - dc) of energy output for a 2 to 4-hour discharge and has an open circuit voltage of 108 volts.

Prior to the Energy Commission contract, ZBB focused its efforts on configuring the components into a vertical arrangement to minimize the footprint of the module. A significant engineering effort was undertaken to simplify the manufacturability of the module by dividing the major components into three separate pre-assembled sections. The lower section contains the electrolyte storage tanks, the middle section consists of the pumps and electrical control box and the upper section supports the cell stacks. Previous designs had the cell stacks positioned between a set of electrolyte storage tanks in a horizontal arrangement. The vertical design reduced the footprint from 28 ft^2 to 12.8 ft^2, and eliminated the need for a racking system to support a second level of modules. The redesigned module also allowed 500-kWh of energy storage to be packaged into the same container that formerly housed 400-kWh. Figure 1 shows the sectional design of a 50-kWh module.

Figure 1: 50-kWh ZESS Module

The electrolyte storage tanks are rotationally molded from High Density Polyethylene and inserted into a structural frame that comprises the lower section of the module. The middle section consists of a second structural frame, which contains a support plate with the electrolyte circulation pumps and an electrical box for the module control system.

Self-priming centrifugal pumps with AC motors and variable frequency motor drives are used to circulate the electrolyte. An embedded single board computer in the control box coordinates the operation and safety of the module. The computer manages electrolyte liquid levels and monitors leak sensors, voltage and temperature. It also monitors the performance of the module by comparing measured parameters to preset limits. If the measured parameters fall outside the preset values, variables such as pump speeds will be adjusted to compensate. The single board computer also reports module data and receives commands from the ZESS host controller at the 500-kWh system level.

The upper section of the module consists of a framework that supports the cell stacks and the associated plumbing manifold system. A key feature of the flowing technology is that the cell stacks, where the electrochemical reaction occurs, can be easily replaced at a fraction of the initial system cost. Figure 2 demonstrates the installation of the upper cell stack section to the main structural portions of the module.

Figure 2: Cell Stack Installation

A 500-kWh ZESS provides a meaningful amount of energy storage for utility applications. To achieve this, ten 50-kWh modules are aligned in two independent strings on each side of a standard 20 foot cargo container. The container has full side opening, bi-fold doors on both long sides to allow access to the modules. A string of five modules aligned on one side of a shipping container is shown in Figure 3. The container, PCS and cooling equipment are mounted on a 45-foot flatbed trailer for operation and transportation to site as shown in Figure 4.

Figure 3: String of five modules aligned in ZESS container.

Figure 4: 500-kWh ZESS

The ZESS unit is rated at 500 kWh of energy storage with a continuous power rating of 250 kW that can be sustained for 2 hours. The ZESS can achieve higher currents with a peak power output of 500 kW, which is the rating of the PCS. Specifications for the ZESS are shown in Table 1.

Table 1: ZESS specifications

	50-kWh Module	500-kWh ZESS
DC Interface	120 Volts (dc) max 108 Volts (dc) open circuit	600 Volts (dc) max 540 Volts (dc) open circuit
Energy Capacity	50 kWh (2-4 hour rate)	500 kWh (2-4 hour rate)
Power	25 kW continuous / 50 kW peak	250 kW continuous / 500 kW peak
Configuration	Three cell stacks connected electrically in parallel	10 modules 2 parallel strings of 5 modules in series
Dimensions	44″W x 42″C x 78″H	20′L x 8′W x 8′6″W
Weight	3,000 pounds (estimated)	40,000 pounds (estimated)

A 500 kW/625 kVA PCS, supplied by SatCon Power Systems, is mounted to the back end of the trailer. The two-stage unit, comprised of choppers and inverter/converter, enables the bi-directional flow of power from the ZESS to the electrical grid. The inverter was designed for three phase output connection of 480Vac, 60Hz operation. The DC cables travel from the PCS through conduit underneath the flatbed trailer to the ZESS container. Two overhead cable trays that extend from the ceiling and run from one end of the ZESS container to the other are used to support the DC cables.

The PCS supplies AC power from the grid to the ZESS container for the control system, pumps, chillers, lighting and other electrical loads. A host controller located in an electrical box at the end of the container, controls the operation of the 500 kWh ZESS by managing the PCS functions, monitoring the individual modules and archiving data.

At the bottom of the ZESS container are two separate spill containment sumps that run the entire length of the container, one for each string of modules. Each sump is designed to hold the entire contents of a module in the case of a spill.

Exhaust fans at both ends of the container circulate air through the container. Two chillers, each rated at 2 tons of cooling capacity, supply coolant to each module through a heat exchanger in the electrolyte storage tanks. Coolant lines travel from the chillers, which are mounted at the front end of the trailer, through the wall of the container to the modules. Two sets of manifolds that run the length of the sumps are used to distribute the coolant to the individual modules.

Outcomes or Results:

Factory Testing of the 500 kWh ZESS

Factory testing of the first 500-kWh ZESS unit was initiated in September 2005. The performance of the ZESS was verified by performing a standard baseline cycle, which consists of charging the ZESS for 4.5 hours at 150 amps (each string), then discharging at 150 amps until the ZESS reaches 60 volts (1.0 volts per cell). The cut-off point for a string of modules occurs when any module in the string reaches 60 volts during discharge. During a complete baseline performance cycle, the unit discharged for nearly 4 hours and achieved energy output in excess of the 500 kWh (dc) rating. Voltage profiles for the two strings during a baseline cycle are shown in Figure 5.

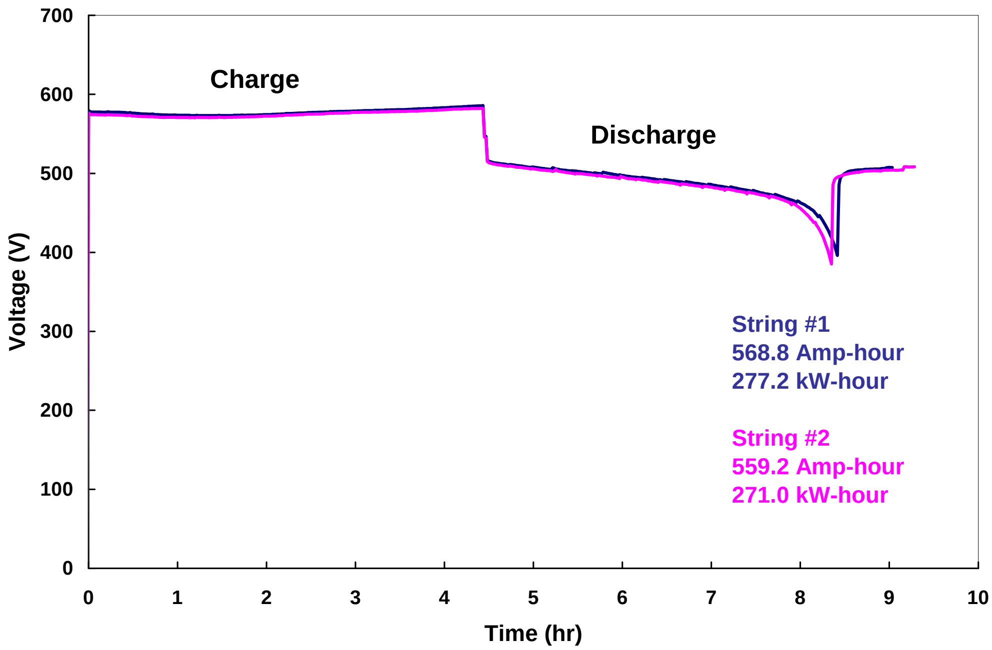

Figure 5: Voltage profiles for each string of a 500-kWh ZESS.

The ZESS can be charged or discharged at either a constant current or a constant power. The system will also perform load following operations by utilizing input from grid monitoring current and potential transducers (CT's and PT's) allowing real-time "peak shaving" operations.

In a separate test, the AC and DC power output from a single string was measured at various output currents during discharge of the ZESS (See Figure 6). The difference between the AC load and the DC load is associated with the power draw from the PCS and the auxiliary equipment needed to operate the ZESS.

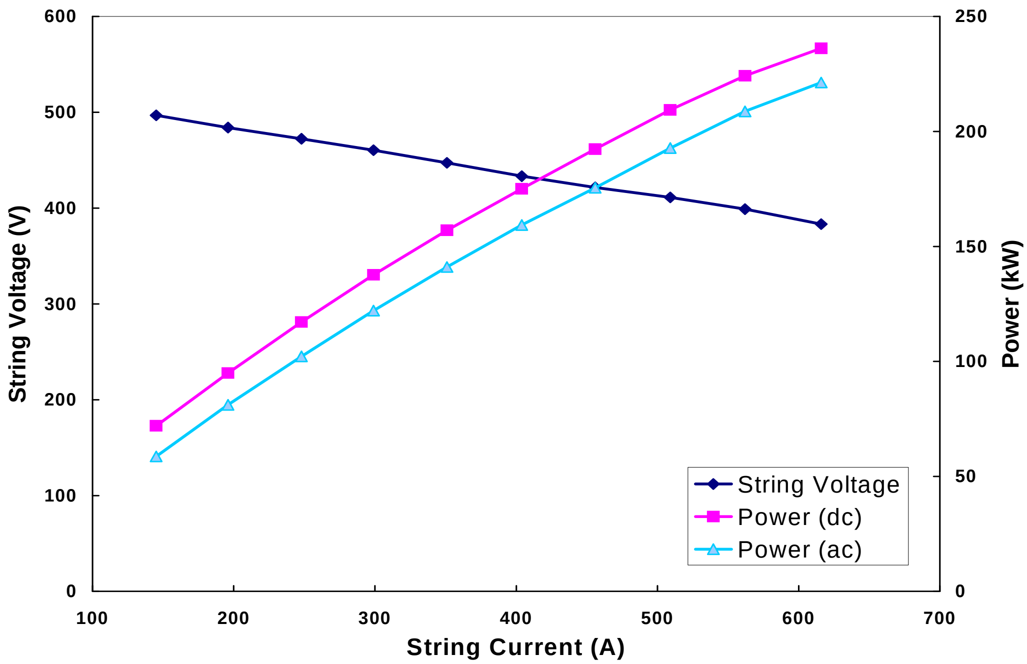

Figure 6: Power Characteristics for a 250-kWh string

First Factory Acceptance Test

In late September 2005, representatives from Distributed Utility Associates (DUA) inspected and tested the operation and safety of the first 500-kWh unit. As a result of this testing, hardware and software modifications were made and additional testing was required before the ZESS would be considered acceptable.

An additional test was also added to the factory test plan, which demonstrated the reliability of the system by completing 10 consecutive charge discharge cycles without interruption.

From January 5, 2006 to January 15, 2006, a series of 10 consecutive cycles were performed without interruption on the first 500-kWh demonstration unit. This set of tests was required by PG&E to demonstrate the reliability of the system. The ZESS completed five full baseline cycles, and then the system was allowed to strip (fully discharge) for one day. This test sequence was designed to simulate cycling five days per week, followed by a strip cycle over the weekend. Voltage profiles for the ten consecutive cycles are shown in Figure 7. The unit achieved greater that 500 kWh (dc) total energy output during each of the 10 cycles.

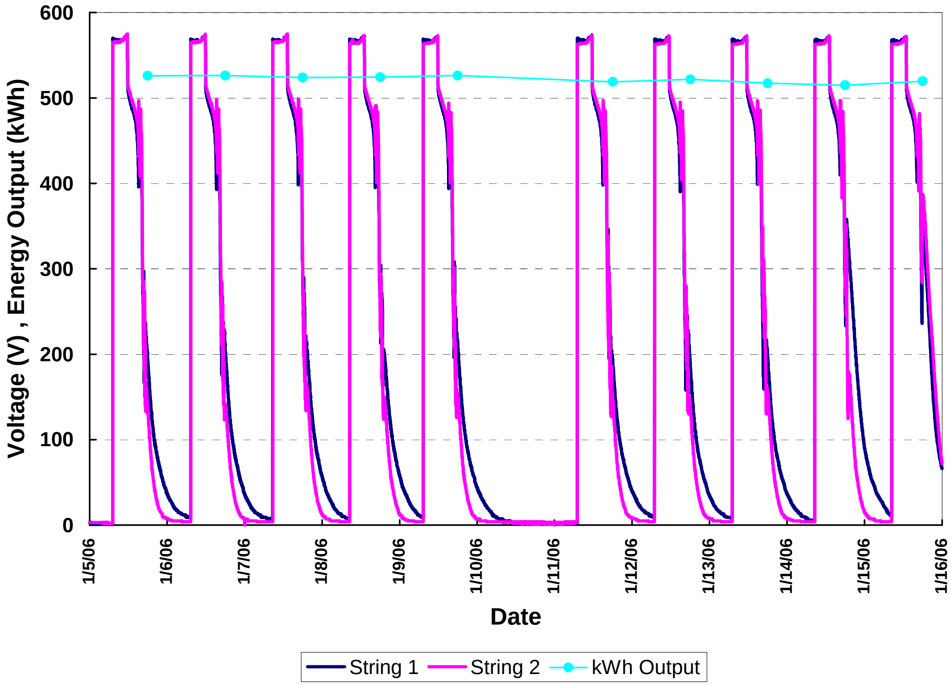

Figure 7: Ten consecutive cycles performed on the 500-kWh ZESS.

Second Factory Acceptance Test

Representatives from the United States Department of Energy (DOE), Garth Corey of Sandia National Laboratories and PG&E's DUIT test facility (Ben Norris of Distributed Utility Associates) performed the witness testing of the 500-kWh ZESS unit on January 25, 2006. The witness testing consisted of the following tests:

Performing a 250 kW (ac) discharge on each individual string, equivalent to 500 kW (ac) total
Measuring the AC power for the auxiliary loads.
Discharging at 250 kW (ac) for the entire unit until the ZESS shut off.
Performing a partial strip cycle
Partially recharging the ZESS

Each string was discharged individually at 250 kW by putting the other string off-line, and requesting 500 kW from the pull down menu in the software. The output from each string was measured at 240 kW (ac), while the total auxiliary load for the unit was measured at 20 kW (ac). When power output is compensated for the auxiliary load of the other string, the total output for each string is 250 kW (ac), giving a total capability of 500 kW (ac) for the system.

The actual power output from the system during the constant power discharge was measured at 245 kW (ac) using handheld meters. When discharging the system at 245 kW (ac), the batteries discharged for a total of 1.55 hours before module #3 reached the low voltage cut-off of 60 volts. This gave a total energy output of 380 kWh (ac). This does not include the initial 250 kW (ac) discharges (less than 5 minutes) for each individual string, which produced an additional 20 kWh (ac) of energy. The total output for constant power discharge tests was 400 kWh (ac) / 440 kWh (dc).

At the end of the 245 kW (ac) constant power discharge, a significant amount of energy still remained in the modules. The modules were then discharged at 150 amps until they reach 60 volts, producing an additional 60 kWh (dc) / 50 kWh (ac) of energy from the system. The total output for the system (constant power discharge followed by constant current discharge) was slightly greater than 500 kWh (dc) / 450 kWh (ac). The AC/DC power and voltage/current profiles for the witness testing are shown in Figures 8 and 9 respectively.

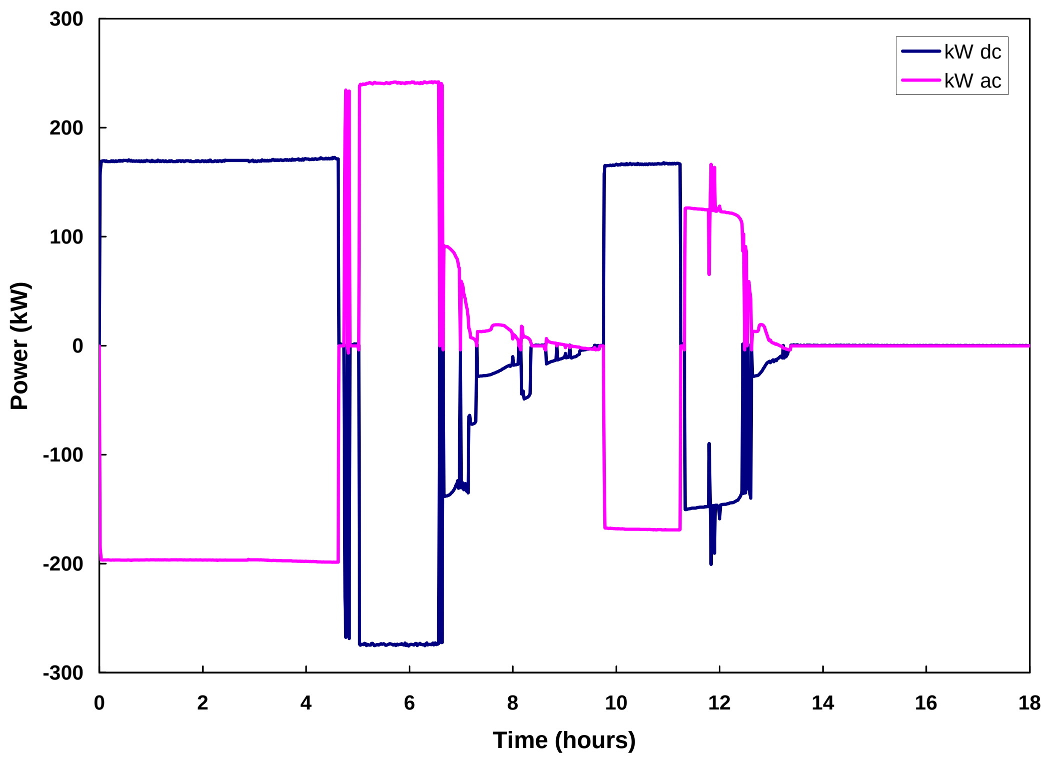

Figure 8: AC and DC power during factory witness testing.

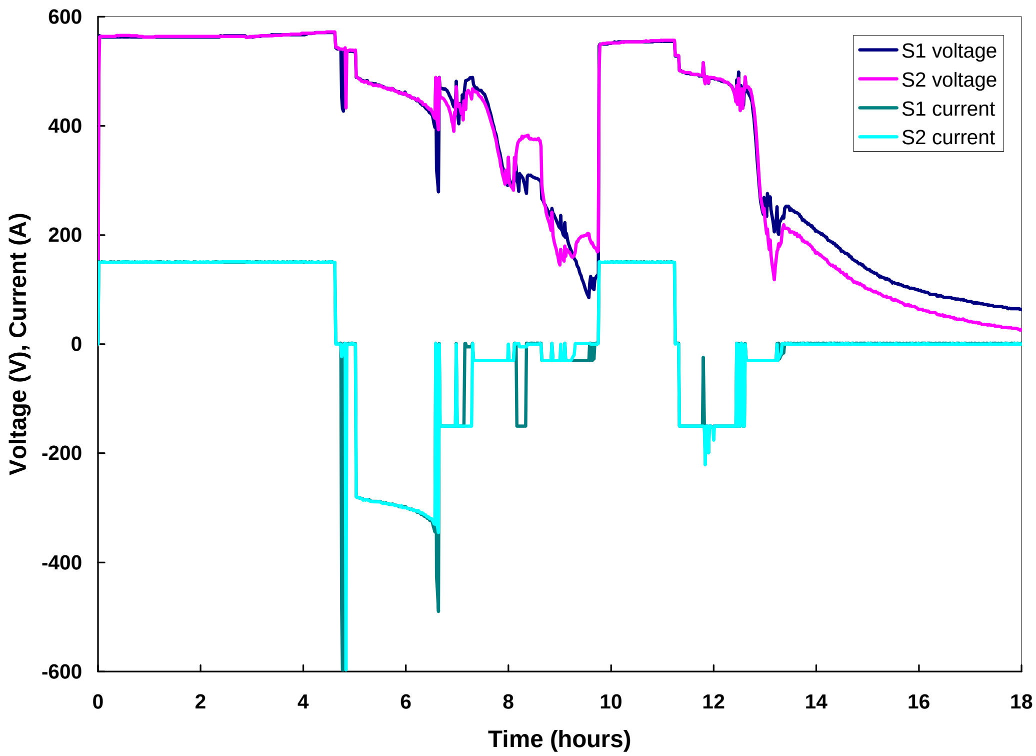

Figure 9: DC voltage and current during factory witness testing.

Based on the results of the witness testing and recommendations of the DOE and DUA, the Energy Commission approved shipping the first 500kWh/500kW unit to PG&E's Designated Test Facility (DUIT).

Transportation of System to Site

It was necessary to secure the modules to the shipping container to prevent shifting during shipping. The 10 modules were anchored to the shipping container by fastening 8′ x 2″ x 1/4″ thick steel tube through the forklift openings in the modules. Ten support tubes were bolted on both ends through corresponding holes in the forklifts slot and the sump I-beams. To stabilize the modules over the length of the shipping container, blocks were placed between modules (near the top) and straps were used to secure the modules together. This locking mechanism enabled the ZESS to be transported successfully to the DUIT facility without any shifting or damage to the individual modules.

DUA and PG&E had originally planned to set the trailer-mounted system in place at the DUIT test facility using a crane. After arrival at the site, it was decided that the system could be backed into position using a standard semi truck cab. In order to maneuver the trailer into the proper location, the position of the back wheels on the trailer were moved. When this was done, the electrical conduit from the PCS unit to the ZESS, which is under the trailer, was damaged. This was repaired and the design was later changed to utilize a flexible conduit connection between the ZESS and the PCS. The installation and location of the 500-kWh ZESS at the DUIT facility is shown in Figures 10 and 11 respectively.

Figure 10: The 500-kWh ZBB being put in place at the DUIT test site.

Figure 11: The 500-kWh ZESS installed at the DUIT test facility.

Major Project Delays

Two quality issues delayed the delivery of unit #1 by six months:

- Stack end block molding/manufacturing
- Tank and containment quality

Stack End Block Molding/Manufacturing (December 2004)

50% of the stacks produced for the first unit were found to leak several weeks after passing their initial quality acceptance tests. The problem was traced to a distorted end block, which is formed from two pieces that were welded together. Corrective action involved milling the top portion of the stack after the welding process to assure a flat surface for welding. The stacks were repaired or replaced.

Electrolyte Tank and Containment Issues (July 2005)

The initial production of tanks and the stacking frames that enclosed the tanks passed all dimensional and physical requirements. However, in the transition from initial prototype to high volume production, dimensional errors encountered on the stacking frames and voids were discovered on some of the rotational molded tanks. These issues were corrected by switching suppliers on both designs after giving the original suppliers the opportunity to correct the defects.

Contract Clarifications (March 2005)

The original schedule for the contract didn't directly specify needed Factory Acceptance Tests (FAT) of the ZESS unit at the ZBB test facility prior to shipping the unit to the demonstration site. On March 29, 2005 the California Energy Commission and ZBB Energy Corporation participated in a meeting at the Energy Commission offices in Sacramento to discuss the status of the demonstration project. A clarification was made to the schedule to reflect the SOW, to include factory and acceptance testing at the ZBB test facility.

Factory Testing Acceptance Criteria (October 2005)

After a number of conversations between the key participants in the contract regarding the testing of the ZESS at the ZBB test facility, representatives from the Energy Commission, DOE, Sandia, DUA and PG&E met on November 2, 2005 to discuss the factory-testing plan. The result of the meeting was to provide PG&E with performance data regarding the ZESS and to finalize the testing of the ZESS at the ZBB test facility. The participants agreed that it was only necessary to demonstrate the maximum power capabilities of the system for a short duration as opposed to one full hour as previously proposed. The factory test was accepted with this understanding. The acceptance of the factory test plan caused a one month delay in the program.

3.0 Installation of Storage System at the PG&E Designated Test Facility

The first of the four trailer-mounted ZESS units constructed by ZBB was transported to the PG&E designated test facility at PG&E's San Ramon Site (location of the ongoing DUIT program). The purpose of sending the storage system to this controlled test location was twofold. First, testing the storage system at this site meets the requirements of PG&E to test its integration into PG&E's distribution and communication systems before it was connected to the electric grid. Second, testing at this site would allow PG&E personnel to be trained in the operation of the storage system before it was placed in its commercial substation demonstration site.

Approach or Methods:

PG&E verified the electrical interface requirements and completed the electrical preparations. ZBB prepared the modules and performed initial safety and performance tests for the system. DUA and ZBB also developed a test plan outlining the specific tests to be performed at the DUIT facility

Outcomes or Results:

The trailer-mounted system was originally going to be set in place using a crane, but after arrival at the site, it was decided that the system could be backed into position using a "yard goat", which is a special tractor used to move trailers around and is easier to maneuver than a standard semi truck cab. The ZESS was delivered on February 15, 2006. Initial testing of the system was initiated two weeks after delivery to site. The test plan that was developed under this task was executed in Task 4.0.

4.0 Utility Required Testing and Engineering

The goal of this task was to perform the engineering and analysis work required to prepare the storage system for operation in accordance with the intended application: distribution system upgrade deferral. There was be on-site software development and testing to ensure the system responds correctly to conditions in the field, i.e., it operates when peak load requirements dictate. This development took place in the controlled PG&E test facility environment where dispatching, maximum capabilities, and other potential benefits were tested before going to the commercial demonstration site. It was expected that such testing would reveal additional benefits (e.g., power quality, voltage support, etc.) beyond those already identified once the operations personnel were involved in the controlled environment testing.

Approach or Methods:

Prior to the demonstration of the ZESS at a utility substation, the performance and reliability of the system needed to be verified. A test plan was written to demonstrate the operation of the first 500 kWh units at the DUIT facility and the multiple units' supervisory control at ZBB's facility.

The Test Plan was intended to ensure that the system was fully operational, that it met the functional requirements of the substation application, and that it would perform reliably before installation at a PG&E commercial substation site.

Outcomes or Results:

Testing of Unit #1

Safety Testing

The initial safety checkout was successfully completed in April 2006. This portion of the testing consisted of two stages:

1. Demonstrate module level safety logic, which included shutdown conditions indicated by leak sensors and electrolyte levels in the storage tanks.
2. Demonstrate the alarm signal for a large leak in the sump area below the batteries.

Safety of the individual modules was tested by artificially introducing leak conditions and verifying the system response. The responses included opening the DC contactor and stopping the pumps for the module that experienced the shutdown condition.

Safety at the system level was demonstrated by activating a contact closure that will be used for an audible alarm and external alarm system. This system is externally powered, and its operation is independent of the container control. Eight leak sensors in the sump area of the

ZESS container are used to activate the alarm system. To simulate a leak, the container-level sensors were submerged in a liquid bath. This causes a contact closure that was used for the alarm system.

Calibration of the 500-kWh System

Independent power and energy measurements were made using the Shark 100 meter/transducer manufactured by Electro Industries / GaugeTech, shown in Figure 12. This meter was installed between the PG&E disconnect switch and the ZESS, and provides the ability to easily monitor power and energy. In addition, a test computer recorded ongoing test results.

Figure 12: Shark 100 Meter

The Shark meter was installed and calibrated by PG&E personnel. The unit was used to measure power from the ZESS based upon communications with the PCS. Power readings on the site computer display are compared to the measured values from the Shark meter in Figure 13. The information obtained from this testing was used to recalibrate the ZBB instrumentation.

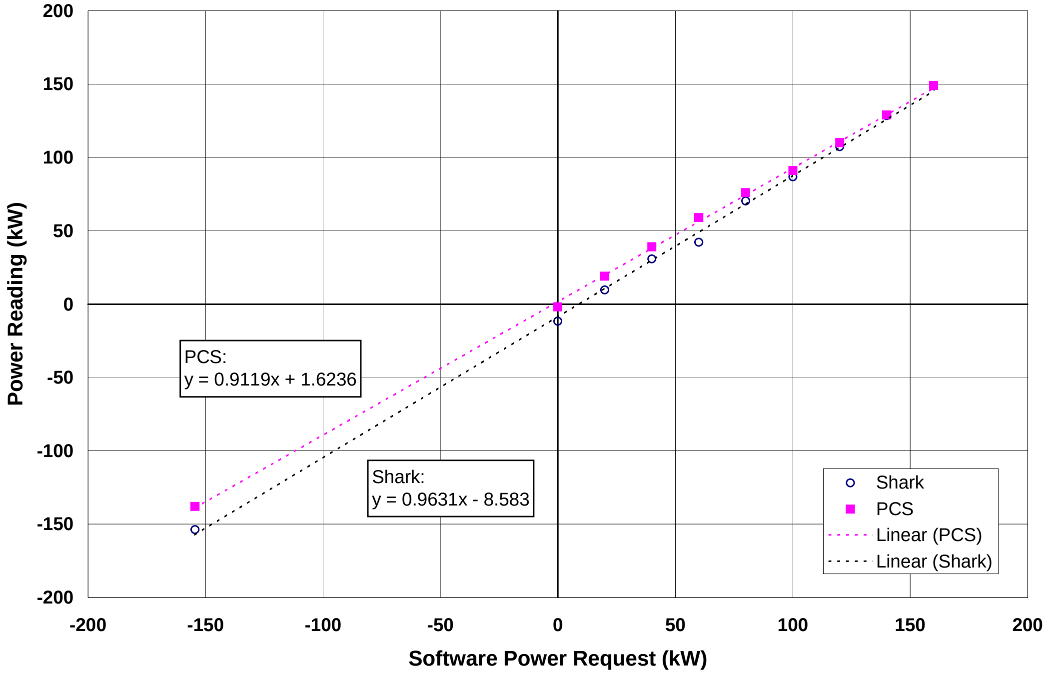

Figure 13: Calibration Curves for 500 kWh ZESS

ZESS Characterization Testing

The operation of the 500-kWh energy storage system was handed over to DUIT personnel and characterization testing of the system was initiated during the month of May 2006. Characterization of the ZESS involved discharging the unit at various rates and measuring the output capacity of the system as shown in Figure 14. As is the case with all energy storage systems, the output capacity declines as the discharge rate increases. The difference between the AC and DC output for the system is primarily due to power conversion inefficiencies and auxiliary loads.

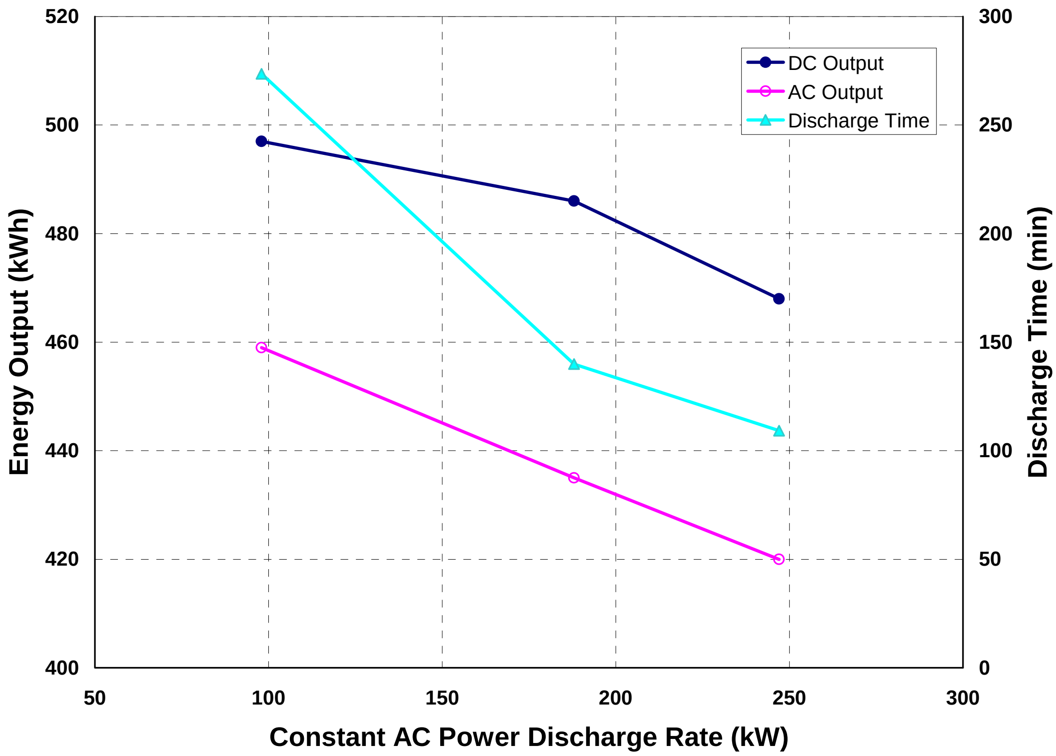

Figure 14: Constant Power Discharge Performance of the 500-kWh ZESS

High Power Test

The test was designed to validate the 500 kW (AC) power rate. To accomplish this, the 500 kW was commanded from the ZESS while the chiller compressors were on. The AC output was measured at the Shark power meter. The unit was found to be capable of outputting 481 kW (ac) for short durations of time, i.e. less than five minutes.

Testing of Unit #2

During the characterization testing of unit #1 at the DUIT test facility, ZBB encountered a number of unforeseen problems, which delayed the progress of the ZESS testing. Some of the issues included intermittent shutdowns, less than anticipated performance, faulty coolant hose and inadequate spill containment. After six months of testing and numerous discussions with the Energy Commission, it was decided to ship an entire system to replace the original unit in the field. The delays caused by the issues are documented in the following sections (Major program delays/issues).

Safety and Performance Testing

Safety tests were completed and capacity tests were performed on unit #2 in August 2007. It achieved 427 kW (ac) and 425 kWh (ac) output during 240 kW (ac) and 160 kW (ac) discharge rates respectively as shown in Figure 15. During previous performance testing, the maximum energy output achieved by the ZESS system was 409 kWh (ac).

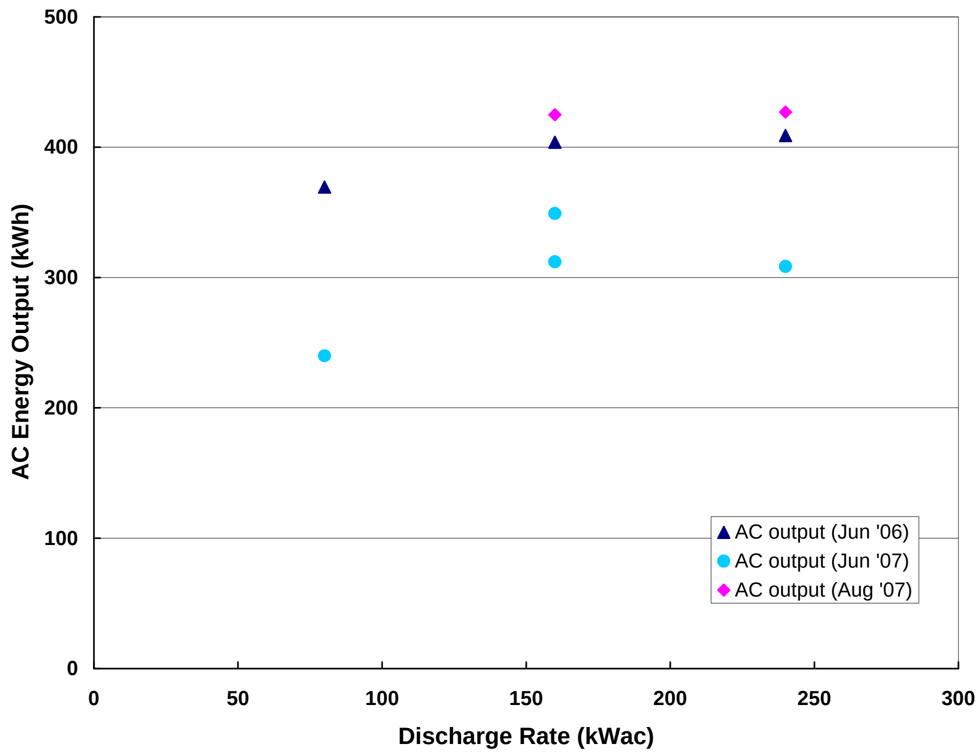

Figure 15: Energy output of 500 kWh ZESS

Reliability Testing

This test was designed to validate the reliability of the system in a load following mode for a Transmission and Distribution (T&D) deferral application in an accelerated test representing a 3-year period. If the duty cycle for this application were 10 operating days per year, a 40-day test period would represent approximately 3 years of field experience.

PG&E substation load profiles were used to create 40 days of diurnal cycling. Simulated profiles were generated based on four different load profiles and a load threshold of 10 MW. The load profiles used for the reliability testing are shown in Figure 16.

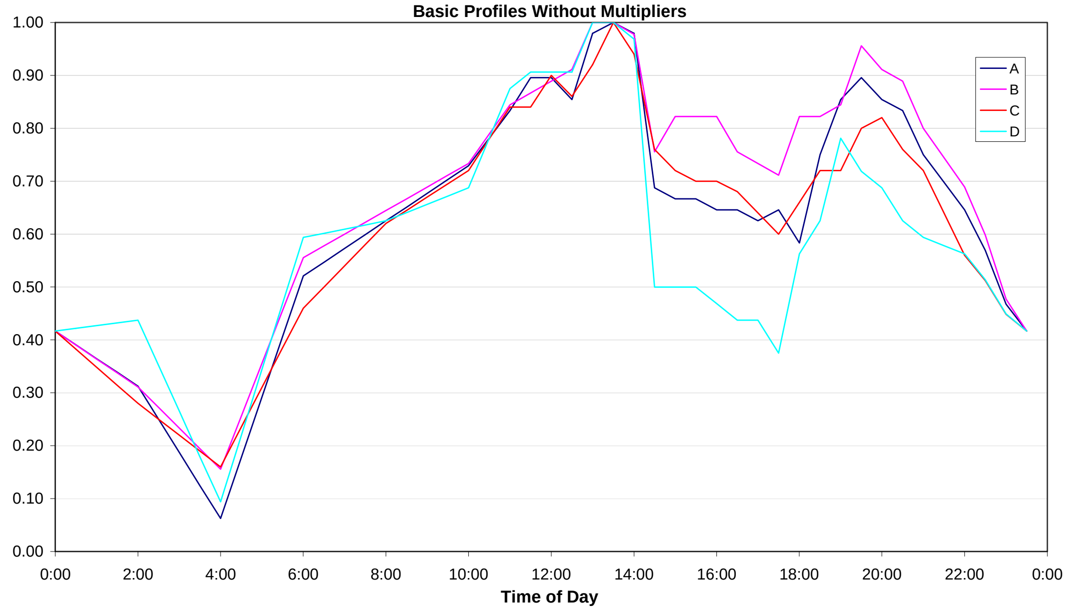

Figure 16: Load profiles generated from PG&E substation data.

The profiles were scaled to achieve various power and energy outputs from the energy storage system. During the load following period of the day, the unit would only discharge, up to 250 kW maximum, if a signal corresponding to a load greater than 10 MW was generated.

The signal generator was set up to read the load data from the file, and then send a 0 to 5 volt signal to the ZESS based on the simulated load. The daily load data files ranged from 0MW to 10.32MW, and the ZESS was to supply power above 10 MW.

A series of cycles were developed (40 days) by randomly inputting one of the four load profiles and a peak load for each day. The loads were designed so that some days the load would be less than the 10MW threshold (no discharge) and some days the load is greater than the output capacity of the ZESS (which is 250 kW). The series of cycles are shown in Table 2.

Table 2: Summary of reliability testing parameters

Test day	Date Performed	Load Profile	Substation Peak (MW)	ZESS Peak Output (kWh)		Test day	Date Performed	Load Profile	Substation Peak (MW)	ZESS Peak Output (kWh)
1	9/11/07	A	10.13	128		21	9/30/07	D	7.92	0
2	9/11/07	B	9.84	0		22	10/01/07	A	10.08	80
3	9/12/07	C	10.20	200		23	10/02/07	B	10.08	80
4	9/13/07	A	9.84	0		24	10/02/07	C	9.84	0
5	9/14/07	B	10.32	320		25	10/03/07	A	10.08	80
6	9/15/07	D	7.68	0		26	10/03/07	B	10.08	80
7	9/16/07	D	7.92	0		27	10/03/07	D	8.4	0
8	9/17/07	C	10.08	80		28	10/03/07	D	7.44	0
9	9/18/07	A	10.08	80		29	10/03/07	C	10.08	80
10	9/19/07	B	9.84	0		30	10/03/07	A	10.08	80
11	9/20/07	C	10.20	200		31	10/03/07	B	9.84	0
12	9/21/07	A	10.08	80		32	10/04/07	C	10.20	200
13	9/22/07	D	8.4	0		33	10/05/07	A	10.08	80
14	9/23/07	D	7.44	0		34	10/06/07	D	8.40	0
15	9/24/07	B	9.96	0		35	10/07/07	D	7.44	0
16	9/25/07	C	10.32	320		36	10/08/07	B	10.08	80
17	9/26/07	A	9.84	0		37	10/09/07	C	10.32	320
18	9/27/07	B	10.08	80		38	10/10/07	A	9.84	0
19	9/28/07	C	10.32	320		39	10/10/07	B	9.84	0
20	9/29/07	D	7.68	0		40	10/10/07	C	10.32	320

Each weekday the ZESS was charged between 7:15am to 11:45 am. The ZESS was not charged on weekends since no discharges were scheduled for those days. Following charge the ZESS goes into a rest mode, waiting for a load signal from the simulation software. If the simulated load goes above 10 MW, the ZESS dispatches energy. If the load signal never goes above 10 MW, the ZESS does not discharge until the load following period is completed at 5:15 pm, at which time the ZESS is fully discharged to remove any remaining energy from the system prior to the next day's cycle.

Load Following Calibration

To calibrate the load following output from the energy storage system, the system was charged and the PG&E software was used to generate signals that were sent to the ZESS in 0.25V increments. The measured output of the system is compared to the simulated load values in Figure 17.

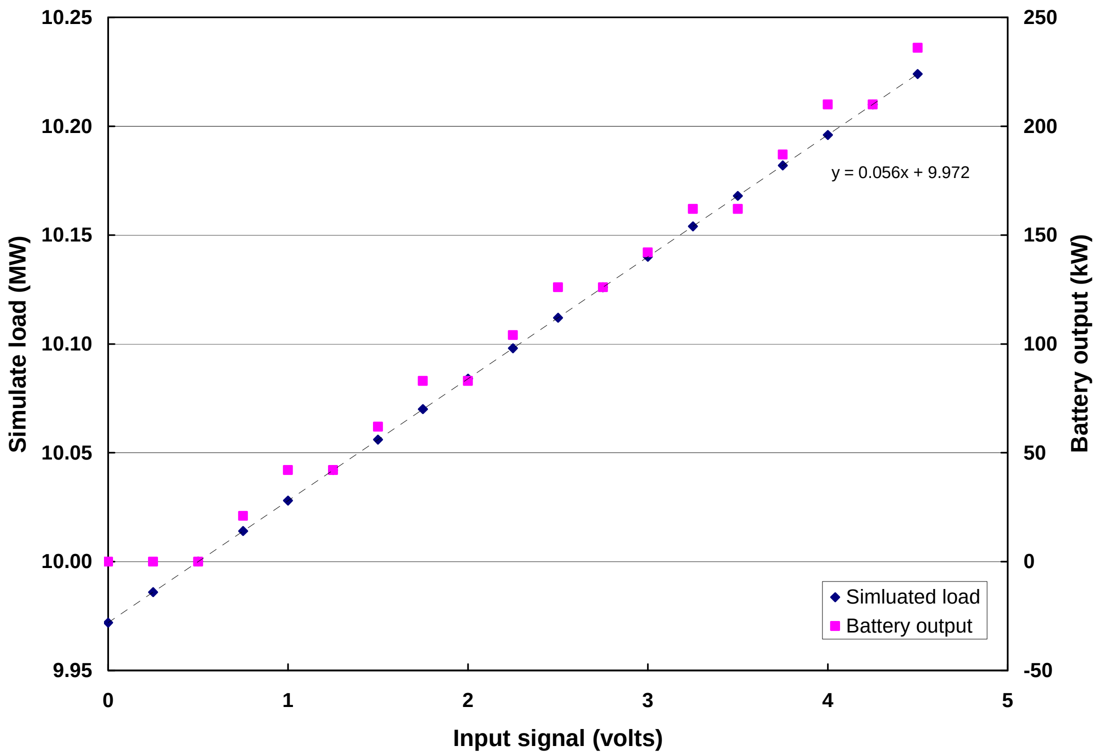

Figure 17: Load following calibration curve.

Reliability Testing Test Results

ZBB successfully completed 40 load following discharge cycles and 29 days of reliability testing for a 500-kWh energy storage system. The ZESS demonstrated the ability to automatically charge during off-peak hours, provide load following discharges when necessary and self-strip without failures or intervention during the test period. It dispatched energy to the simulated load every time that it received a signal from the PG&E simulation program software.

Figures 18 and 19 show ZESS power profiles during 200 kW and 250 kW load following discharge cycles respectively. Figures 20 and 21 expand the load following discharge portions of these cycles.

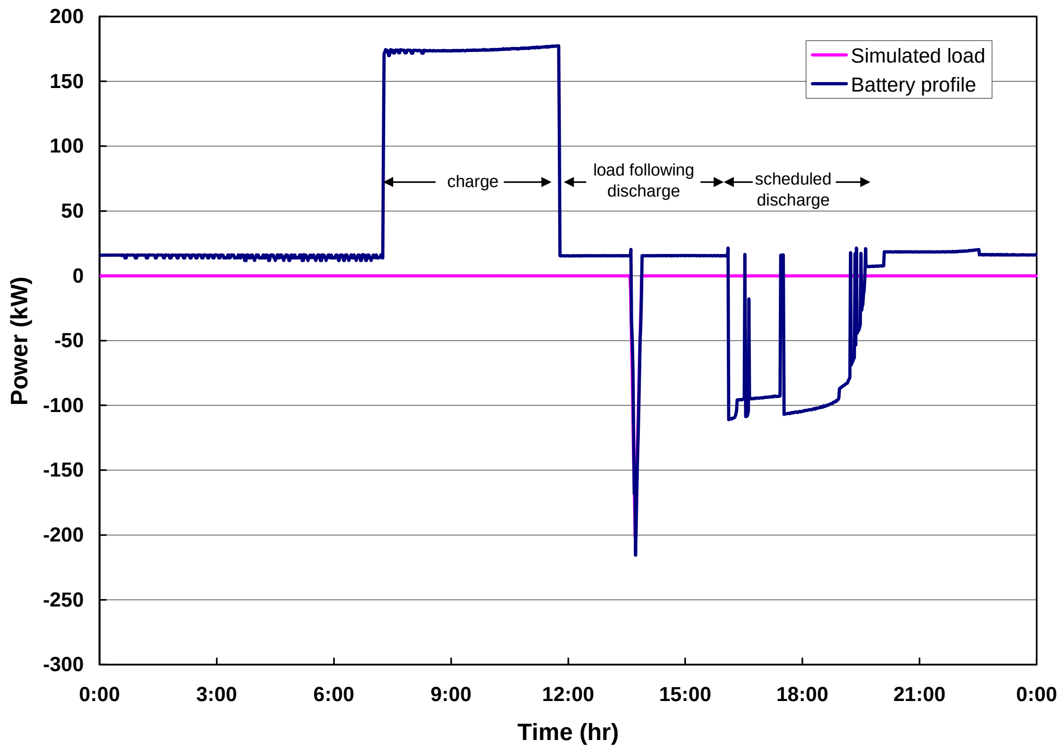

Figure 18: Power profile for 200 kW load following discharge cycle.

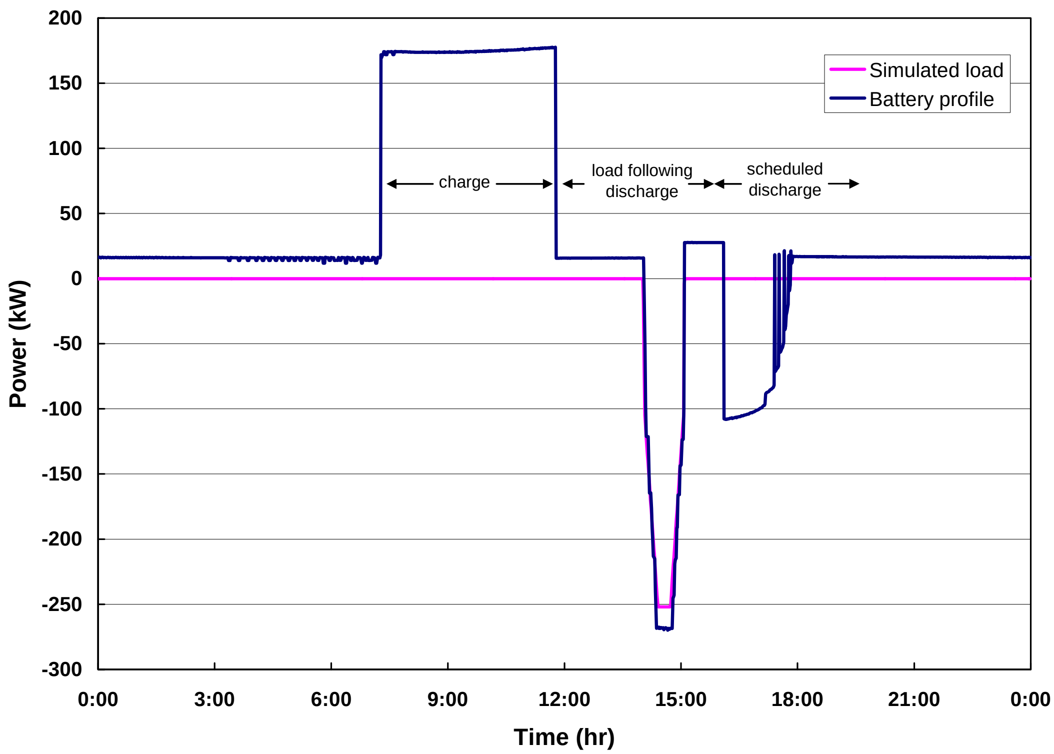

Figure 19: Power profile for 250 kW load following discharge cycle.

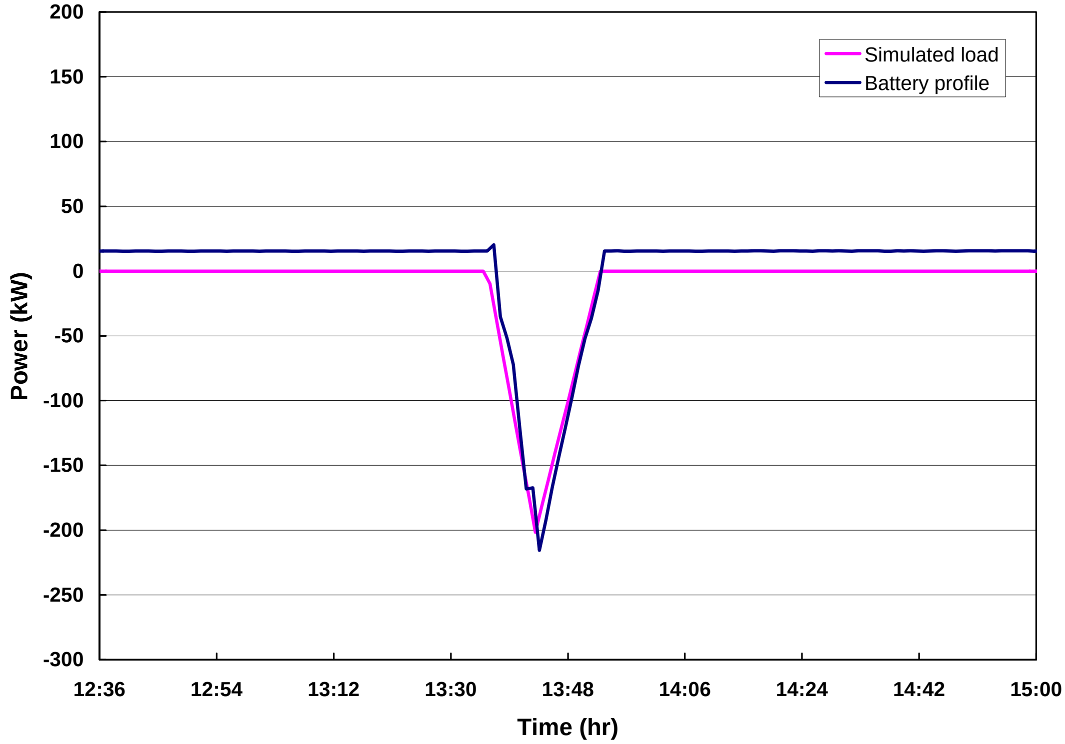

Figure 20: Expanded profile for 200 kW load following discharge cycle.

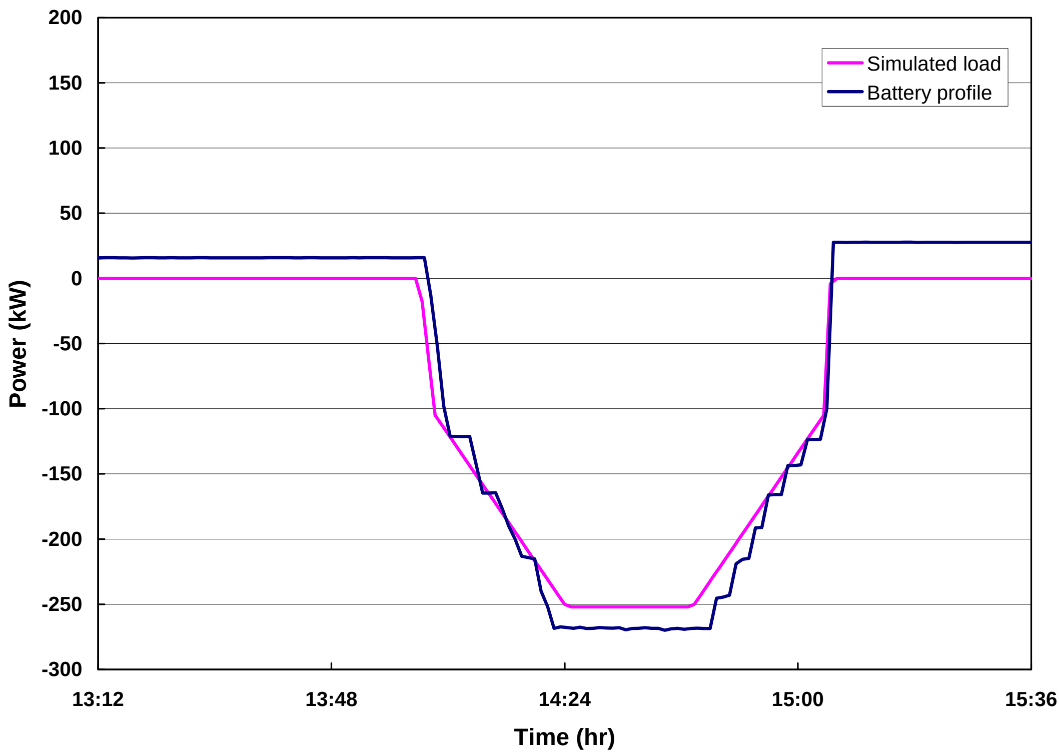

Figure 21: Expanded profile for 250 kW load following discharge cycle.

Prior to initiating the reliability testing of the ZBB unit, PG&E had scheduled unrelated testing of a fault current limiter (FCL) in the High Current Yard at DUIT starting on 10/15/07. In order to complete the load following discharges in less than 40 days, the duration of the test was reduced. Although the total number of test days was reduced, load following discharges were completed by advancing the simulator through the scheduled zero discharge days and by performing multiple discharges on a single charge. This illustrated that the ZESS is capable of multiple load following discharges in a single day period, while allowing the completion of all scheduled load following events.

After completing the first 29 days of the reliability testing, the 500-kWh ZESS unit was disconnected and relocated on October 15 to the secure PG&E parking lot pending completion of the FCL tests.

Future Testing Contract

Following the reliability testing of the system, a number of options for going forward with the program were investigated. Due to delays during the program, ZBB and the Energy Commission determined that the terms of the contract 500-03-031 could not be met without a scope, deliverable and time amendment to the contract. A plan was originally developed to continue the contract with a modified scope, but the Energy Commission later determined that there is not sufficient time or funding to amend the current contract. The best option at this time is to close out the contract and enter into a separate contract, after approvals are received from the Commissioners at an Energy Commission Business Meeting, to evaluate and demonstrate the two previously constructed Energy Storage units.

The goal of this modified project will be to demonstrate the operation of multiple ZESS units, the transportability of the system and to evaluate the economic benefits of using electric energy storage. The new project will consist of a 6 month evaluation of two 500 kWh ZESS units operating as a 1 MWh system. ZBB will assume responsibility of the two 500 kWh ZESS units and associated equipment and software to operate the units during the duration of the project.

The agreement for this effort is due to be initiated after completion of the current contract on March 31, 2008. Effort under this new agreement will continue for a period of 6 months from the beginning of the contract. The contract will consist of ZBB matching funds only and will use two 500kWh Zinc Energy Storage System units from contract 500-03-031 operating as a 1MWh system. However, instead of a new contract, a Letter of Agreement was entered into between the Energy Commission and ZBB for equipment relocation, housing and further research. The Energy Commission authorized ZBB to continue to test and demonstrate the operation of the ZESS at its facility.

Reinstallation into DUIT High Current Yard

After deciding to close out contract 500-03-031, ZBB provided a proposal with several options for future work to the Energy Commission in January 2008. ZBB and the Commission decided to take advantage of the option that was the lowest cost and had the highest benefit to the participants. The option involved:

1. Reinstalling unit #2, which was being stored in the PG&E parking lot, into the high current yard where it was tested previously
2. Perform safety and performance testing on the unit in San Ramon.
3. Decommission, transport and reinstall the second unit at the ZBB test facility to demonstrate the transportability of the system.
4. Test both units for a 4-5 month period according to a modified test plan from Contract 500-03-031. Testing will include safety, performance and multiple container testing.

After deciding on the option for going forward, ZBB was informed that the DUIT High Current Yard would be available for 2-3 weeks before PG&E needed the yard for alternative testing. The ZESS was moved into the yard and electrically connected on February 11, 2008. After some minor maintenance on the unit, the system was started up and the safety tests were performed the next day. A short charge/discharge cycle was performed on February 12 and characterization testing was initiated on February 13.

After 4 month of total inactivity (outdoor with no power to the unit), the system operated at essentially the same level as it did prior to the shutdown and relocation of the unit. Three tests were performed on the unit including a 150-amp discharge, a 160 kW discharge and an 80 kW discharge. The average output from the unit for these three cycles was about 6 kWh (1-2%) higher than before the shutdown. Also, the order from highest to lowest performance for the individual modules was essentially the same as it was previously. There was a slight change in the performance order for the top four performing modules. This test demonstrated the ability of the system to sit dormant for months and be able to operate at the same level in a very short amount of time.

Following the short test period, Unit #2 was prepared for shipping back to the ZBB test facility. Decommissioning and preparation for shipping the unit was completed in two days. Unit #2 was shipped from San Ramon on February 29 and arrived at the ZBB test facility one week later.

Major Program Delays/Issues

Personnel Issues (April 2006)

ZBB reported to the Energy Commission on April 19, 2006 that Mike Hughes, project engineer, had been unexpectedly admitted to hospital with a serious medical condition. ZBB was advised that Mr. Hughes might be incapacitated for up to 10 weeks. ZBB initiated actions to bolster its project team, including transferring its lead engineer from Australia to temporarily assist in the continuation of the project. Mr. Bjorn Jonshagen assisted the project in Milwaukee during the month of May 2006 and has given input for the entire duration of the project. From May until November 2006, Mike Hughes was only available on a limited basis.

Coolant Line Failures (April 2006)

After completing the safety testing on unit #1, both chillers were found to have overflowed a small amount of coolant. After investigating the situation, it was determined that two of the 10 modules had coolant line leaks. It was decided to ship modules M1 and M7 back to ZBB for repairs. This caused the testing to be delayed for about one month.

When the modules arrived in Milwaukee, the coolant lines for both modules were inspected, and both modules were found to have pinhole leaks in the convoluted Teflon tubing used for the coolant loop. The tubing was replaced in both modules, the electrolyte was circulated and both batteries were cycled to demonstrate that the modules were operating properly. The modules were shipped back to the DUIT facility and the 500-kWh system was operational within one month after the modules had been removed from the unit.

Further investigations of the coolant line showed a problem with the way the Teflon tubing had been packaged by the vendor. The vendor packaged five lengths of tubing in a box and stapled the box closed. When pressurizing lengths of tubing that had been back-ordered, the top piece in the box was flawed from the staples and leaked in several locations. As a result of this testing, all coolant lines are now pressurized to 20 PSI prior to installation in a module.

Spill Containment and Float Issue Action Plan (July 2006)

In July 2006, an incident occurred where a small amount of electrolyte (less than one gallon) spilled onto the ground outside of the container. The external spill was handled in accordance with PG&E normal clean up operations and there was no residual effect to the site or any environmental impact of any sort. Testing of the ZESS demonstration system was halted until the situation had been thoroughly analyzed and improved safety measures had been developed.

After reviewing the situation, ZBB concluded that the levels in the electrolyte tanks for module #1 became uneven, causing the pumps to shut down as they should have. Over the weekend, the electrolyte from inside the cell stacks slowly drained into the electrolyte storage tanks. Since the electrolyte levels in the tanks were severely imbalanced at the time of the shutdown, the anolyte tank eventually overflowed. A connection between the tanks should have allowed electrolyte to flow from one tank to the other, but in this case, the electrolyte escaped out through the vapor vent on the anolyte tank.

The liquid from the vent ran down the front and side of the tank and onto the support I-beam for the sump area. The majority of the liquid went into the sump area, while a portion spilled outside the ZESS container and onto the ground at the DUIT facility. The spill containment needed redesign to ensure that any electrolyte spilled from the system would be contained inside the container.

The electrolyte spill was the result of three different factors:

1. The module was not properly controlling the electrolyte levels in the tanks.
2. The design of the tie line between the tanks caused the liquid to escape through the bromine filter as opposed to transferring to the other electrolyte tank.
3. The spill landed on the I-beam, which allowed liquid to travel both into the sump and out toward the door of the container.

ZBB designed a solution to assure that liquids are retained in the sump and implemented measures to assure proper monitoring of electrolyte levels.

ZESS Performance (June 2007)

After discussions with the partners of the Energy Commission demonstration project it was determined that the project deadline of August 31 could no longer be met and that ZBB would need to develop a new plan of action. A strategic plan was developed to thoroughly examine the float issues and spill containment and to implement changes to the remaining ZESS systems.

The suspect module was returned to Milwaukee. Investigation showed that a pull down resistor in the float circuit was disconnected, indicating that it was probably poorly or loosely connected at the DUIT site. When operating the module in this condition at the ZBB facility, the same level control problem that caused the spill was encountered. The levels in the electrolyte storage tanks separated, causing a shutdown condition for the module. The poor electrical connection effectively kept the anolyte speed float input at 5 volts regardless of the position of the float itself. The pump speeds remained constant, as opposed to the normal operation where the pump speeds are varied to maintain constant electrolyte levels in the tanks. The end result was no level control and the electrolyte in the catholyte tank became low enough to set off the low float shutdown.

Because of problems associated with the initial test unit at the DUIT test facility during the first year of testing, ZBB and the Energy Commission agreed to ship an entire system rather than to ship replacement modules and retrofit unit #1 in the field. The replacement of the ZESS unit with a new unit was considered a maintenance action rather than a modification of the contract.

After thoroughly investigating the causes of the spill and determining the necessary modifications to the ZESS, a Critical Project Review (CPR) was scheduled for the program. At the CPR, it was decided that the best option to complete the demonstration site testing of the ZESS unit was to:

- Implement the modifications to a new 500-kWh ZESS unit
- Test the unit at the ZBB test facility according to the factory test plan
- Demonstrate the load following ability of the unit
- Ship the new unit to the DUIT test site
- Return the original unit to ZBB to retrofit with upgrades.

The second unit was shipped in May 2007. The implementation of the spill action plan, modifying and testing the new ZESS unit and replacing the unit on site caused a ten month delay in testing of the system at the DUIT demonstration site.

After installation of the second ZESS unit at the demonstration test site, tests were performed to determine the output capacity of the ZESS at different discharge rates. The ZESS operated continuously for two weeks without incident, but the performance of the new unit was lower than anticipated.

Individual cell stack current measurements and visual inspection of the electrolyte fluid flow indicated probable internal shorting of a number of cell stacks. Based on the poor performance during the baseline and characterization cycles and the indication of internal cell stack leakage, ZBB determined that the cell stacks should be replaced.

New cell stacks were manufactured during the months of July and August 2007 and the cell stacks were replaced in late August. The process of manufacturing and installing new cell stacks caused a 2-3 month delay in the testing program.

Further investigation showed that the flow frame material used to make stacks in early 2007 was found to be 20% lower in tensile strength and flexural strength than previous materials. ZBB has modified the acceptance criteria and tightened the specifications for the cell stack material that will prevent this from happening in the future.

5.0 Pre-Commissioning Data Collection at Utility Demonstration Site

The goal of this task was to gather data at the user site. This would document the problem to be solved by the installation of energy storage and provide input to the benefits analysis. The data would also help guide the design and optimization of interfaces and procedures for operation of the EES.

Approach or Methods:

ZBB would work with the end-user (PG&E) to gather load data and interface requirements at the utility site where the storage unit would be installed.

Outcomes or Results:

PG&E collected data on a number of potential sites. PG&E was unable to commit to a demonstration site until completion of the ZBB Test Plan at the DUIT facility. Due to delays in the program, a demonstration site was never established since there was insufficient time to complete the testing at a utility demonstration site. Data from one potential site was utilized in developing the load following software used in Task 4.0.

6.0 Installation of Storage System at Utility Demonstration Site

The goal of this task was to install the fully functional ZESS at the host utility demonstration site (the exact location was to be determined by PG&E), to demonstrate acceptable performance in the field, and to commission the facility so that the demonstration period may commence.

Approach or Methods:

PG&E would verify the electrical interface requirements and complete the electrical preparations. ZBB would prepare the modules and performed initial safety and performance tests for the system before training and handing the operation over to PG&E representatives.

Outcomes or Results:

Due to delays in the program, a demonstration site was not established since there was insufficient time to complete the testing at a utility demonstration site. The ZESS was not installed at a utility demonstration site.

7.0 Data Acquisition System and Benefits Data Reporting Requirements

The goal of this task was to provide system level operation and performance information, including economic performance information, about this project to the public. This goal was to be achieved through the use of a Data Acquisition System (DAS) and additional reporting requirements to the standard PIER reporting requirements contained in Administrative Tasks 1.4 and 1.6 and Agreement Attachments A-1 and A-2.

Approach or Methods:

The DAS benefits and data reporting requirements involved the preparation and implementation of a DAS Implementation Plan, Test and Reports.

Outcomes or Results:

A DAS implementation plan was prepared, but it was not implemented since the ZESS was not tested at a utility demonstration site.

8.0 Technology Transfer Activities

The goal of this task was to develop a Technology Transfer Plan to address how the knowledge gained from this effort was to be shared with industry, California ratepayers, potential customers and other interested parties.

Approach or Methods:

Results and findings were shared with the Energy Commission through formal reporting documents such as the final report. In addition, presentations and publications in public forums were offered to inform appropriate individuals, organizations and agencies of the progress achieved during the project.

Outcomes or Results:

The goal of this task was to present information at a meeting or conference at least once per year over the duration of the contract. Information was presented at a number of conferences since the kick-off meeting in 2004 including:

- Clean Equity Monaco 2008 Conference, February 20-21, 2008.
- New York Society of Security Analysts (NYSSA), 5th Annual Alternative Energy Conference, New York, November 29, 2007.
- Electrical Energy Storage Applications and Technologies (EESAT) 2007 Conference, San Francisco, CA, September 23-26, 2007.
- Noble Financial Renewable Energy Equity Conference 2007, Charleston, SC, August 21, 2007.
- Empire Financial Equity Conference, Jamaica, June 14, 2006.
- Electrical Energy Storage Applications and Technologies (EESAT) 2005 Conference, San Francisco, CA, October 17-19, 2005.

Conclusions

ZBB Energy Corporation manufactured and tested two 500-kWh advanced energy storage systems. Unit #1 was manufactured from 2004 to 2005. The unit was factory tested and then tested at the DUIT facility during 2006. A number of obstacles were encountered which delayed the progress of the contract. After six months of testing and discussions with the Energy Commission, it was decided to ship an entire system to replace the original unit in the field.

An alternate unit was built and shipped to the DUIT site in April 2007. The test plan was completed according to the contract in October 2007. The unit provided 427 kWh of energy output and a peak power output of 481 kW for short durations of less than 5 minutes. The energy storage system demonstrated reliability by automatically charging during off-peak hours, providing load following discharges when necessary and operating without failures or intervention during the test period. It dispatched energy to the simulated load every time that it received a signal from PG&E's simulation program software.

The ZESS unit was moved after its reliability testing and was relocated to its original location four months later. The unit performed satisfactorily after this dormant period.

Due to delays during the course of the program, after completion of the DUIT test plan there was not sufficient time or funding to test the entire 2-MWh system in the field at a PG&E designated test site. A DAS implementation plan was prepared to examine the economic benefits of the energy storage system, but it was not implemented since the ZESS was not tested at a utility demonstration site.

Recommendations

A number of options for going forward with the program were investigated. ZBB and the Energy Commission determined that the terms of the contract 500-03-031 could not be met without a scope, deliverable and time amendment to the contract. It was decided that the best option at this time was to close out the contract and enter into a Letter of Agreement between the Energy Commission and ZBB for equipment relocation, housing and further research. The Energy Commission authorized ZBB to continue to test and demonstrate the operation of the ZESS at its facility.

Public Benefits to California

The primary benefit from ZBB's energy storage technology to California electricity ratepayers is in the form of reduced electricity rates. At present, standard utility practice is to invest capital dollars from electricity rates in T&D equipment (infrastructure) to ensure adequate peak capacity in the transmission and distribution systems to serve customer load. This involves considerable up-front expense, which may not be recouped through rates for many years. The use of targeted, properly operated distributed storage, in amounts necessary to meet only the load increases, can be a more cost-effective alternative, deferring infrastructure upgrades and thereby reducing capital investment costs.

Indirect benefits to California electricity ratepayers include distribution system support. This support comes in the form of frequency and voltage control provided by storage systems. Storage systems can be more efficient and cost-effective than large, centrally located power plants. The net result is reduced operations and maintenance costs.

Additional benefits are summarized below:

Feature: ZESS can be left in a fully discharged state for extended periods of time.
Related benefit: Cost of inventory and cost of storing the systems is relatively low since the systems do not need to be constantly charged.

Feature: ZESS has a modular arrangement and design.
Related benefit: This allows the system to be easily transportable to sites and facilities where it may be needed. For example, a ZBB Energy storage system can be moved easily to a location needing short term peak power or where voltage instability is an issue.

Feature: ZESS acts in a peak-shaving capacity.
Related benefit: Fewer and shallower "brown outs" for public customers due to increased reliability of the power system. Deferral of costly capacity upgrades which may be ultimately passed on to public ratepayers.

Feature: ZESS has a small footprint (space-efficient).
Related benefit: The system can be installed in crowded or smaller substation facilities without expanding or building out expensive accommodating space.

Feature: ZESS technology is essentially ready for commercialization and scalable in 50 kWh to 500 kWh increments.
Related benefit: Systems can be scaled for small industrial to large utility applications.

Feature: There are no heavy metals and virtually no vapor emissions from the system.
Related benefit: ZESS technology is environmentally friendly and can be located anywhere.

Feature: The ZESS provides return on investment (ROI).

Related benefit: Use of the storage system on a 10-year basis could result in about $2.8 million in savings (NPV), with a benefit/cost ratio of about 1.08 (given today's storage system costs). For mature ZESS systems, the B/C ratio is estimated to be about 2.64.

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Abbreviations and Acronyms

AC	Alternating Current - described as voltage and current varying with time
Amp (A)	Ampere – a measure of electrical current
ATC	Available transfer capability
B/C	Benefit-to-cost ratio
Br	Bromine
Btu	British thermal unit
Energy Commission	California Energy Commission
CPR	Critical Project Review
CT	Current transducer
DAS	Data Acquisition System
DC	Direct Current – described as non-time-varying voltage and current
DG	Distributed generation
DOC	Depth-of-charge
DOE	Department of Energy
DR	Demand Response
DUA	Distributed Utility Associates
DUIT	Distributed Utility Integration Test
DVBE	Disabled Veteran Business Enterprise
EES	Electric Energy Storage
EESAT	Electrical Energy Storage Applications and Technologies
Electrolyte	Liquid solution capable of conducting electric current
EPRI	Electric Power Research Institute
FCL	Fault Current Limiter
FCR	Fixed Charge Rate
GW	Gigawatt
GWh	Gigawatt hour
HVDC	High voltage direct current
Inverter	Electronics system that converts DC power to AC power
ISO	Independent System Operator
kV	Kilovolt
kVA	Kilo-volt-ampere
kW	Kilowatt - one thousand Watts of power
kWh	Kilowatt-hour - energy equal to 1 kW for one hour
LED	Light emitting diode
MVA	Mega-volt-ampere
MW	Megawatt - one million Watts of power
MWh	Megawatt hour - energy equal to 1 MW for one hour
NPV	Net present value
O&M	Operation and maintenance - or the associated costs

PCS	Power Conversion System
PG&E	Pacific Gas and Electric Company
PIER	Public Interest Energy Research
PowerPlus	Anaheim-based technical support contractor for ZBB Energy Corporation
PT	Potential transformer
PUC	Public Utility Commission
R&D	Research and Development
RD&D	Research, Development & Demonstration
SNL	Sandia National Laboratories
SOC	State of charge
State of the Art	Most advanced technology of its type currently available
T&D	Transmission and distribution
Turn-key	Supplied to the end-user in a fully operational state
UL	Underwriter's Laboratory
UPS	Uninterruptible power supply
VAR	Volt-ampere-reactive
Volt (V)	Measure of electrical potential
Watt (W)	Measure of power
WBS	Work Breakdown Structure – a project management tool
ZBB	ZBB Energy Corporation
ZESS	Zinc Energy Storage System
Zn	Zinc